Effects of COVID-19 pandemic on the sound environment of the city of Milan, Italy: a comparison of the pre, during and post lockdown periods

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Abstract
Limiting the diffusion of COVID-19 pandemic in Italy required the adoption of different restrictive measures. These interventions produced significant reductions of vehicular traffic and, consequently, of the traffic noise levels. The permanent noise monitoring network installed in the city of Milan, developed by the European LIFE+ project DYNAMAP, has captured the sound environment changes throughout the pandemic period. The monitoring sensors are equipped with a built-in software able to identify Anomalous Noise Events (ANE) to discard the contribution of non-traffic noise sources from the dynamic noise map computation. In this work, we analyse two representative network sensors from January 2019 to June 2021, thus embracing the pre, during and post "hard" lockdown periods. The results show a relevant increase of both the absolute noise levels (L_{den}) and presence of ANEs during the summer of 2020, as well as a progressive increment of L_{den} during the subsequent periods, but without returning to the pre-COVID-19 levels.

Keywords: sound environment, COVID19 pandemic, noise monitoring network, road traffic noise, anomalous noise events

1 Introduction

The pandemic outbreak of COVID-19, originated in Wuhan, China, at the end of 2019, fully revolutionised people's lifestyle. Smart working from one side and the imposition of social distancing on the other, caused implications on health and wellbeing. Italy experienced a first "hard" lockdown period from March 10, 2020. All non-essential commercial activities, businesses and industries were temporarily shut down, forcing people to "stay at home". As a consequence, the pandemic slowed down, almost disappearing thereafter. Later, the infections started up again in 2020 autumn season with the resulting restrictions and lockdown according to the trend of daily new cases with the infection and the rate of occupation of intensive care. Table 1 shows the time line of measures taken by the Italian Government in reply to COVID-19 pandemic. These measures consisted in restrictions, advices and alerts with different level of seriousness.

During the outbreak, the acoustic community organised engaging public organizations and academics to collect noise data through pre-existing noise monitoring networks and on-going measurements (e.g., see [1–3]). In Milan and Rome, Italy, a permanent noise monitoring network allowed to capture the changes in the sound environment engendered by the lockdown measures. This network of acoustic sensors has been developed within the framework of the European LIFE+ project DYNAMAP [4]. DYNAMAP is a dynamic noise mapping system able to detect and represent in real time the acoustic impact of road infrastructures in urban and suburban areas using a limited number of noise monitoring sensors, permanently installed in the area of study [5]. To this aim, the monitoring stations are provided with a built-in software named Anomalous Noise Event Detector (ANED) [6], designed to identify the presence of non-traffic related events, denoted as Anomalous Noise Events (ANEs) within the DYNAMAP project (e.g., trains, sirens, birds, people, street works, etc.). The ANED algorithm is designed as a two-class classifier trained with acoustic data gathered from the network of sensors to discriminate between ANE and Road Traffic Noise (RTN) according to their spectro-temporal characteristics [7]. Following the project specifications, these events are detected and removed from the computation of the A-weighted equivalent noise levels every second so as to represent the RTN levels in the dynamic noise maps reliably [4]. District 9, in the city of Milan, is one of the two pilot areas chosen for the implementation of the system [8]. The second pilot area is located in a suburban area of Rome [9]. In Milan, the DYNAMAP network is composed of 24 sensors, which have been appropriately distributed all over District 9.

Table 1 – Phases and measures taken by the Italian Government, through the emanation of DPCMs (Decree of the President of the Council of Ministers), Ordinance of the Ministry of Health and Regional Ordinance, in reply to COVID-19 pandemic.

LAW MEASURES – PHASE 1
Action 1: DPCM 23/02/2020 - effect: schools closed in Lombardia (Region)
Action 2: DPCM 01/03/2020 - effect: manifestations suspended, restaurant and entertainment venues partially closed, partial limitation of work activities
Action 3: DPCM 08/03/2020 - effect: restaurant and entertainment venues closed, banned hangouts, greater limitation of work activities
LAW MEASURES – “HARD” LOCK-DOWN
Action 4: DPCM 22/03/2020 - effect: total limitation of work activities, obligation to stay at home (except for basic necessities)
LAW MEASURES – PHASE 2
Action 5: DPCM 03/05/2020 - effect: first partial reopening of work activities
Action 6: DPCM 17/05/2020 - effect: second partial reopening of work activities
Action 7: DPCM 03/06/2020 - effect: third partial reopening of work activities and displacements between regions
LAW MEASURES – PHASE 3
Action 8: DPCM 15/06/2020 - effect: fourth partial reopening (no schools and public offices)
LAW MEASURES – PHASE 4
Action 9: Regional Ordinance 10/7/2020 - effect: reopening of sports and recreation centers (gyms, swimming pools and spas, cinemas and theatres, etc.)
Action 10: Regional Ordinance 16/8/2020- effect: closure of dance halls, discos and similar venues
Action 11: 14/9/2020 - reopening of schools
LAW MEASURES – PHASE 5
Action 12: DPCM 13/10/2020 - effect: bars and restaurants with table service only (closing at 9 pm), nighttime consumption on public land prohibited, parties prohibited, for private homes it is forbidden to receive more than 6 people
Action 13: Regional Ordinance 21/10/2020 - effect: travel prohibited (curfew) from 11pm to 5am, shopping centers close on weekends
Action 14: DPCM 24/10/2020 - effect: closure of high schools, closure of recreation centers (gyms, swimming pools and spas, cinemas and theaters, etc.)
RED ZONE (LOCK-DOWN)
Action 15: DPCM 3/11/2020 - effect: total limitation of work activities, obligation to stay at home (except for basic necessities), travel prohibited (curfew) from 10pm to 5am
ORANGE ZONE (“SOFT” LOCK-DOWN)
Action 16: DPCM 28/11/2020 - effect: limitation of work activities and displacements, partial reopening of basic necessity commercial activities, travel prohibited (curfew) from 10pm to 5am. More restrictions for the Christmas period.
YELLOW ZONE
Action 17: Ordinance of the Ministry of Health 12/12/2020 - effect: reopening of the restaurant service with consumption at the table (until 6pm), travel prohibited (curfew) from 10pm to 5am
ORANGE ZONE (“SOFT” LOCK-DOWN)
Action 18: Ordinance of the Ministry of Health 8/1/2021
RED ZONE (LOCK-DOWN)
Action 19: DPCM 16/1/2021
ORANGE ZONE (“SOFT” LOCK-DOWN)
Action 20: Ordinance of the Ministry of Health 23/1/2021
YELLOW ZONE
Action 21: Ordinance of the Ministry of Health 29/1/2020

ORANGE ZONE ("SOFT" LOCK-DOWN)	
Action 22: Ordinance of the Ministry of Health 27/2/2021	
RED ZONE (LOCK-DOWN)	
Action 23: DPCM 13/3/2021	
ORANGE ZONE ("SOFT" LOCK-DOWN)	
Action 24: Ordinance of the Ministry of Health 10/4/2021	
YELLOW ZONE	
Action 25: Ordinance of the Ministry of Health 22/4/2021	
LAW MEASURES – PHASE 6	
Action 26: from 24/5/2021 - effect: reopening of shopping centres, gyms, etc..	

In preliminary studies, DYNAMAP data gathered from January to June 2020 were analysed to evaluate the impact of the COVID-19 pandemic on the sound environment of both pilot areas [10,11]. In Milan, the comparison of the noise levels, with respect to the same period of 2019, showed a reduction of the noise levels of approximately 6dB. In Rome, an average difference of 5.2dB during the whole day (L_{den}) and 5.4dB at night (L_{night}) were also observed. The study about the distribution of ANEs in both environments was also conducted, but limited to two representative days (a weekday and a weekend day) during the "hard" lockdown period, showing they remained similar to what was observed before the lockdown in Milan (with a slight noticeable decrease in the weekday), whereas presenting an averaged increase of 20% in Rome (mainly in the weekend day).

This paper is a follow-up research from the previous analyses focused on studying the effects of COVID-19 pandemic on the sound environment of Milan. To that effect, we analyse the evolution of the noise levels and the presence of ANEs at two representative sites of the DYNAMAP noise monitoring network in the District 9 of Milan. The analysis period includes, besides the previous analysed interval (January-June 2020), the period up to June 2021, thus, embracing the pre, during and post "hard" lockdown periods.

2 Data collection from the urban monitoring network

The DYNAMAP monitoring network composed of 24 noise sensors is active since August 2017. The available dataset allows us to keep as baseline 2019 data for evaluating the effect of the pandemic on the sonic environment. Among the 24 monitoring stations, we selected two sites with different characteristics:

- hb127 (Via Quadrio): sensor installed on a school building façade facing the roadside. The road is classified as type D (mainly local traffic, low vehicle flow rate, no heavy vehicles). It is settled in a residential and tertiary urban area with absence of production sites (see Fig. 1).
- hb140 (Viale Jenner): sensor installed on a public building façade facing the roadside. The road is classified as type F (thoroughfare road, high vehicle flow rate, presence of heavy vehicles). It is settled in a residential and tertiary urban area with presence of parks, craft activities / shops, absence of production sites (see Fig. 1).

In the following Table 2, we present the scheme adopted for the analysis of the data recorded from each monitoring stations.

Table 2 – Data analysis

Period considered	Data treatment	Noise indicators
Period analysed:1 January 2020-18 June 2021	Identification of missing data due to sensor off-line or temporary out of use	L_{den} total, L_{den} upon ANED filtering, and percentage of ANEs detected by the ANED algorithm
Reference period:1 January-31 December 2019	Removal of noise data for days with unfavourable weather (rain rate > 2mm/h and wind speed > 5 m/sec) obtained by cross-checking ARPA (Regional Agency for Environmental Protection) Lombardia weather stations	

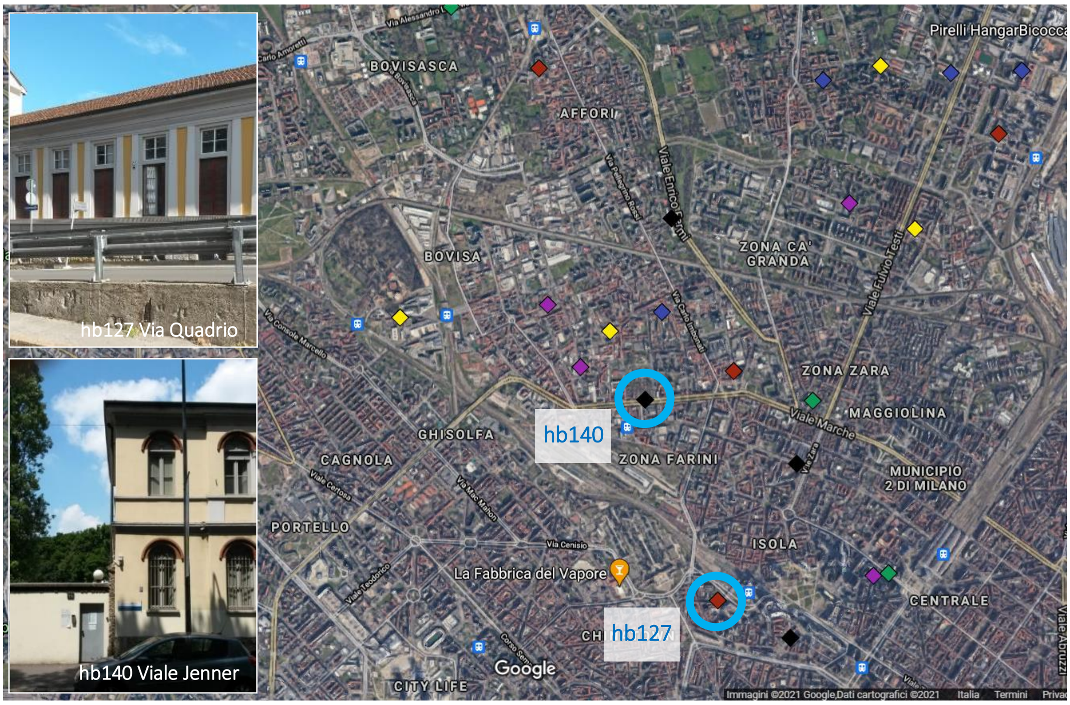

Figure 1 – Google Earth's® view illustrating the position of hb127 (Via Quadrio) and hb140 (Viale Jenner).

3 Experiments and results

3.1 Analysis methodology

Noisemote® is a real-time control service for environmental noise embedded in the DYNAMAP system[1]. It allows displaying dynamic maps, the evolution of noise levels recorded by the monitoring stations, download noise data at different integration time (L_{eq} 1 sec, L_{eq} 5 min, L_{eq} 15 min, L_{eq} 1 h, L_{den} daily, etc.) for both all data (total) (in which all types of noise sources are considered) and ANE-filtered data (in which only the contribution of RTN is retained after removing the ANEs identified by the ANED algorithm). Following [10,11], we analyse both types of data, comparing the L_{den} indicator calculated with and without the ANE contribution, and the averaged presence of ANEs per day in percentage (hereafter denoted as ANE (%)).

Table 3 reports the time-line of the periods corresponding to the Italian and Regional Government measures in reply to the pandemic. These time intervals will be considered for the analysis hereinafter.

Table 3 – Time intervals corresponding to the periods between the different Italian and Regional Government measures considered for the analysis of noise levels.

Analysed periods	Date
1 - before first action (normal situation)	01/01/2020 - 23/02/2020
2 - between first and second action	24/02/2020 - 01/03/2020
3 - between second and third action	02/03/2020 - 08/03/2020
4 - between third and fourth action	09/03/2020 - 21/03/2020
5 - between fourth and fifth action (first "hard" lock-down)	22/03/2020 - 03/05/2020
6 - between fifth and sixth action	04/05/2020 - 17/05/2020
7 - between sixth and seventh action	18/05/2020 - 02/06/2020
8 - between seventh and eighth action	03/06/2020 - 14/06/2020
9 - between eighth and ninth action	15/06/2020 - 10/07/2020
10 - between ninth and tenth action	11/07/2020 - 16/08/2020

[1] http://www.life-dynamap.eu/dynamic-maps/

11 - between tenth and eleventh action	17/08/2020 - 13/09/2020
12 - between eleventh and twelfth action	14/09/2020 - 13/10/2020
13 - between twelfth and fourteenth action	14/10/2020 - 24/10/2020
14 - between fourteenth and fifteenth action	25/10/2020 - 05/11/2020
15 - Red Zone (lock-down) and Orange Zone ("soft" lock-down)	06/11/2020 - 12/12/2020
16 - Yellow Zone	13/12/2020 - 08/01/2021
17 - Red Zone (lock-down) and Orange Zone ("soft" lock-down)	09/01/2021 - 31/01/2021
18 - Yellow Zone	01/02/2021 - 27/02/2021
19 - Red Zone (lock-down) and Orange Zone ("soft" lock-down)	01/03/2021 - 22/04/2021
20 - Yellow Zone	23/04/2021 - 23/05/2021
21 - towards progressive reopening	24/05/2021 - 18/06/2021

3.2 Results of the L_{den} analysis

In this section, the results of the analysis for both the monitoring stations hb127 and hb140 are reported. Figure 2 illustrates the total L_{den} evolution (including ANEs) over the period 1 January 2019 - 18 June 2021; this period includes: the months prior to the diffusion of COVID-19 in Italy, the first "hard" lockdown period, the initial reopening of all activities and the so-called "second wave" of the pandemic. As it can be observed, the noise level trend follows the impact of human activity and of vehicular flows:

- Pre-first lockdown (2019 and January-February 2020): presence of stationary levels.
- First "hard" lockdown period (March-April 2020): noise levels at minimum.
- Post-first lockdown period (summer 2020): gradual increase of noise levels.
- "Second wave" of the pandemic (autumn 2020 - winter 2021): noise levels are in general always lower than the previous years (before COVID-19 breakout), the noise trend follows the "soft" lockdown/reopening between October 2020 and May 2021.
- Progressive reopening of activities (from May 2021): gradual increase of noise levels.

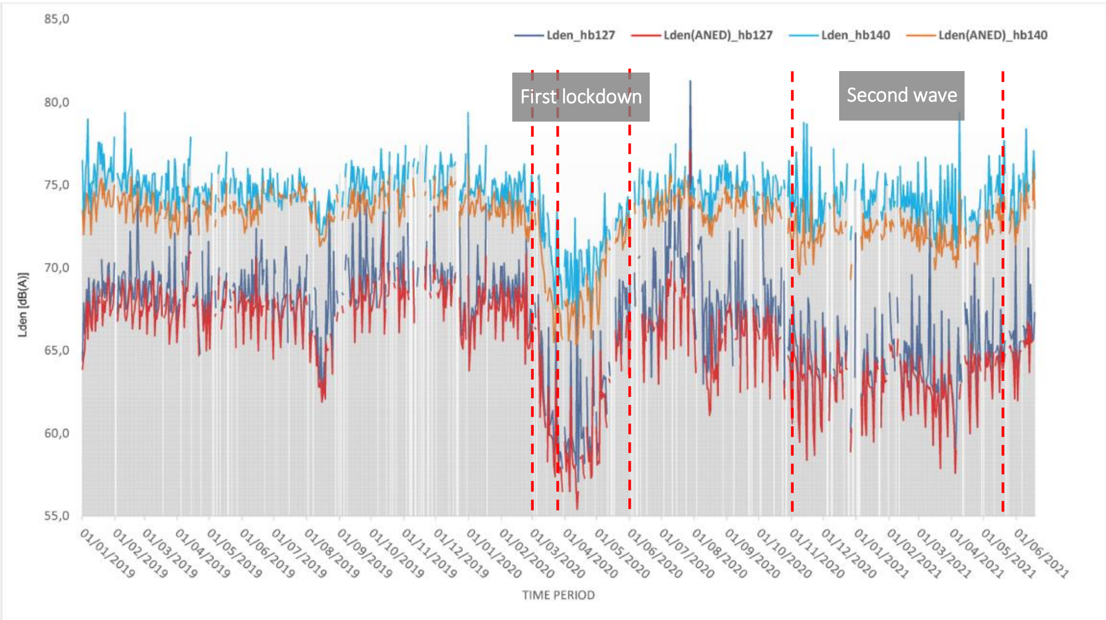

Figure 2: Time evolution of L_{den} levels in the period between 1 January 2019 and 18 June 2021 recorded at the noise monitoring sensors hb127 (Via Quadrio) and hb140 (Viale Jenner). Vertical dashed red lines indicate the entry into force of the main restrictive measures.

Considering the time periods corresponding to the dates of the Italian and Regional Government measures reported in Table 3, in Fig. 3, we analyse the time evolution of the differences (ΔL_{den}) between L_{den} calculated for the reference year (2019) and the corresponding L_{den} for 2020-2021 for each acoustic sensor. Both figures illustrate L_{den} levels accounting for all noise sources, represented as ΔL_{den} total, and L_{den} variation only considering the RTN contribution according to the ANED output, henceforth denoted as ΔL_{den} (ANED).

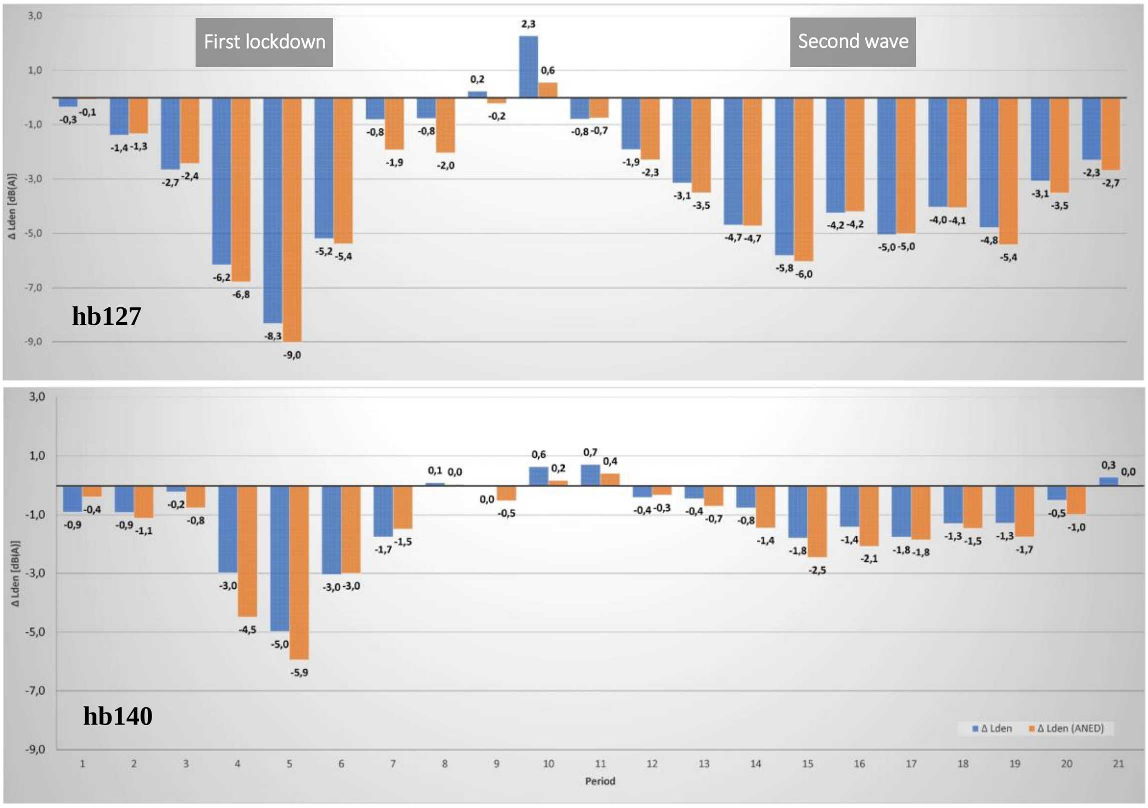

Figure 3: Trend of the differences (ΔL_{den}) between L_{den} levels for the years 2019 and 2020-2021 for the noise monitoring sensors hb127 (Via Quadrio) and hb140 (Viale Jenner). The difference is shown for both L_{den} total and L_{den} (ANED). Each period corresponds to the dates of the different Italian and Regional Government measures reported in Table 3.

In Fig. 2, we can observe how L_{den} levels corresponding to 2019 remain stable over different periods. From 1 January to 23 February (period 1 in Table 3 and Fig. 3), 2019 and 2020 data are aligned, confirming that, in general, the noise trend profiles are almost stationary, thus, suggesting that acoustic-wise 2020, the pre-lockdown period can be considered as “standard”. The first “hard” lockdown, from the end of February 2020, caused a significant reduction of noise (period 4-5 in Table 3 and Fig. 3), with maximum difference of about 9 dB for the total L_{den} for sensor hb127 (via Quadrio) and of about 6 dB for hb140 (viale Jenner). This decrease of noise can be linked to a reduction of the traffic flow down to 90% for via Quadrio and 70% for viale Jenner (since a -3dB level reduction corresponds to a halving of the source sound power level Lw). During the summer of 2020, a strong recovery of road traffic volumes was observed due to both the post-lockdown effect and the economic crisis (people went on vacation less and an increase of noise levels with respect to the 2019 reference period was observed –periods 10-11 in Table 3 and Fig. 3). In the months following 2020 summer, the noise levels retrace the different measures with the rapid succession of openings and closures (periods 12-20 in Table 3 and Fig. 3). The noise level reduction in this period reaches the highest level up to 6 dB (see Fig. 3) for the noise station hb127 and of 2.5dB (see Fig. 3) for hb140. As for the traffic flow along the considered area of study, the observed noise reduction, thus, corresponds to a 75% traffic flow reduction for the site located in via Quadrio and 50% for the site in viale Jenner. In general, the acoustic environment in Milan linked is getting back to normality in periods 20-21 in Table 3 and Fig. 3 (see monitoring sensor hb140 in Fig. 3), but the local viability, influenced by daily movements (e.g., schools), has not yet reached the pre-COVID-19 levels of 2019 (see monitoring sensor hb127 in Fig. 3). The reduction of vehicular traffic (i.e., decrease of background noise) generally corresponds to a greater activity of the ANED algorithm which most likely recognizes more easily extraordinary events not related to road traffic noise, where ΔL_{den} (ANED) > ΔLden.

3.3 Results of the ANE analysis

In this section, we present the results obtained from the analysis of the averaged percentage of ANEs identified by the ANED algorithm per day running in each considered monitoring station, that is, hb127 (Via Quadrio) and hb140 (Viale Jenner). As it can be observed from Fig. 4, the presence of ANEs before the lockdown (period 1 in Table 3) in sensor hb127 (via Quadrio) is very similar to the same period in 2019, subsequently showing a relevant reduction during the lockdown (periods 4-5 in Table 3) as a result of the confinement of the Milan's citizens. Next, periods 2-3 show an increase of ANE (%), probably due to the combination of the reduction of global L_{den} values and an increase of ANEs, e.g., from emergency services and from people caused by the '*fear-of-running-out-of-pantry*' episode highlighted in [10]. After the lockdown, the detection of ANEs increases while the restrictions are progressively reduced, presenting a peak of 12.8% within summer time (period 10 in Table 3). This result is consistent with the greater presence of people in the city during vacations due to the travelling restrictions imposed by the COVID-19 pandemic, being anthropic noise one of the main ANEs detected. The averaged ANE (%) gradually decreases until the end of 2020 (until period 16, see Table 3), subsequently increasing during the progressive reopening in 2021 with respect to what was observed in 2019. Finally, the analysed data present another relevant peak in period 7 (see Table 3) mainly due to an extraordinary episode of 4 consecutive days (from 25/05 to 28/05) where the ANE (%) is higher than 18%. As the audio data are not available in the Noisemote® platform, we cannot determine the origin of the ANEs, but estimations can be done based on the knowledge of the acoustic environment and the restrictions applied for each stage of the lockdown. Our hypothesis is that this result may be caused by street works (or a similar event) during that period due to the high percentage and duration of the episode.

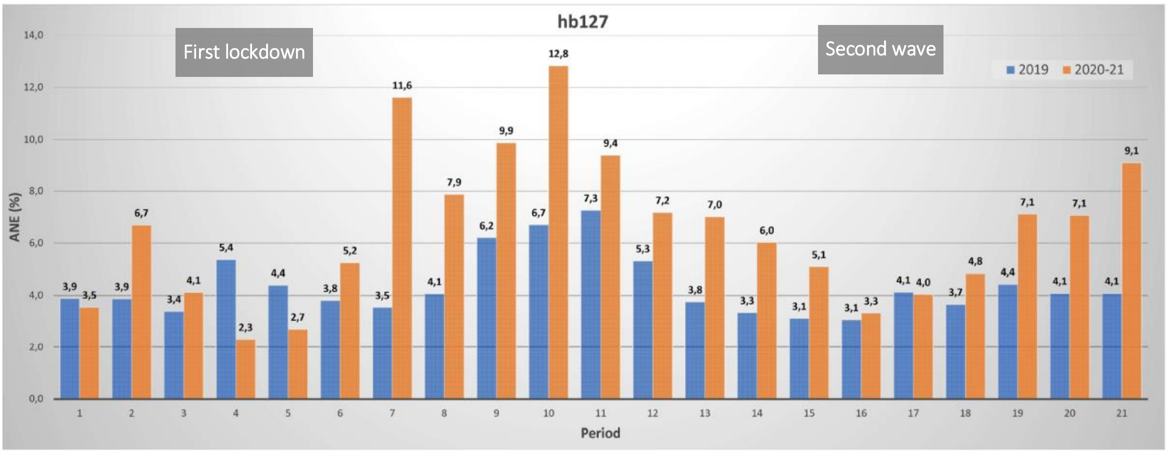

Figure 4 – Distribution of the ANE (%) detected by sensor hb127 (Via Quadrio) along the pre, during and post "hard" lockdown Periods from January 2020 to June 2021 with respect to the corresponding periods in 2019.

In what concerns the impact caused by the presence of ANEs in the via Quadrio's acoustic environment in terms of the averaged correction of the Lden computation of RTN levels (denoted as ANED L_{den} Correction), most values are lower than 1 dB(A) (see Fig. 5). However, it is to note the significant correction of 1.7dB(A) observed during period 10 (in summer) due to aforementioned increment of 6.1% of ANEs in that period. A similar situation can be found in periods 7 and 8 (within the post-lockdown), showing an ANED L_{den} Correction of 1.1dB(A) from +8.1% of ΔANE, and 1.3dB(A) due to +3.6% ΔANE, respectively. Moreover, it is also worth mentioning the correction caused by the presence of ANEs within the lockdown (a period with significant lower L_{den} values as discussed in Section 3.2) entails a variation on the L_{den} measurements of 0.6dB(A) and 0.7dB(A) for period 4-5 (see Table 3), respectively.

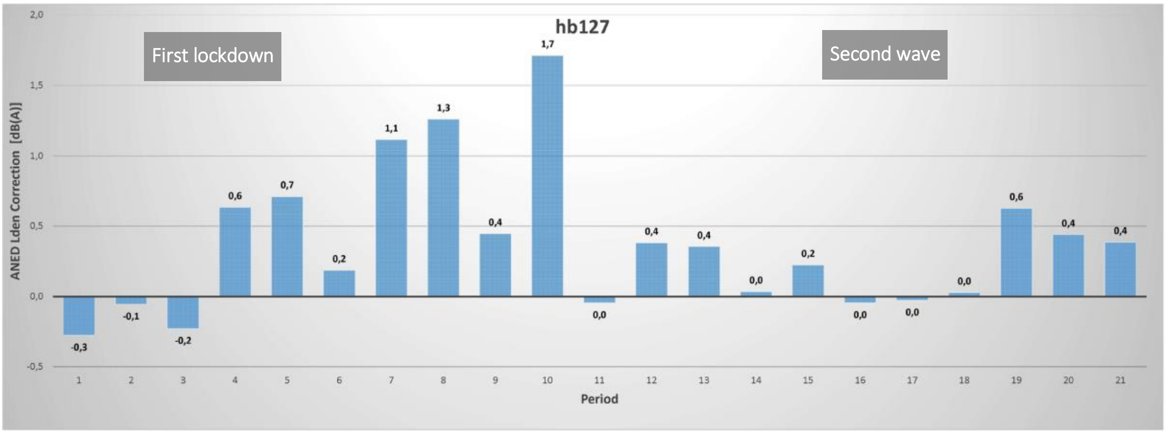

Figure 5 – Correction (in dB(A)) of the L_{den} values measured by sensor hb127 (Via Quadrio) caused by the presence of ANEs along the pre, during and post-lockdown periods from January 2020 to June 2021.

On the other hand, Fig. 6 depicts the averaged percentage of ANEs detected by the ANED algorithm running in sensor hb140 (Viale Jenner) during the pre-, during and post-lockdown periods (see Table 3). Regarding the pre-lockdown, period 1 in 2020 presents a slight but no relevant reduction of the presence of ANEs with respect to 2019. As already observed in sensor hb127, periods 2 and 3 present a significative larger number of events when compared to 2019. This percentage decreases during the lockdown (periods 4-5 in Table 3) and rise progressively during the post-lockdown periods reaching its peak during summer (periods 9 to 11) due the motivation already discussed for sensor hb127. However, notice that the averaged ANE (%), despite being significantly higher than in the surrounding periods in 2020, do not surpass the corresponding values from 2019. After summer, the ANE (%) remains quite similar to what was observed in 2019, although presenting lower percentages until the end of 2020 (periods 12 to 16 in Table 3) and returning to similar values to the reference year afterwards.

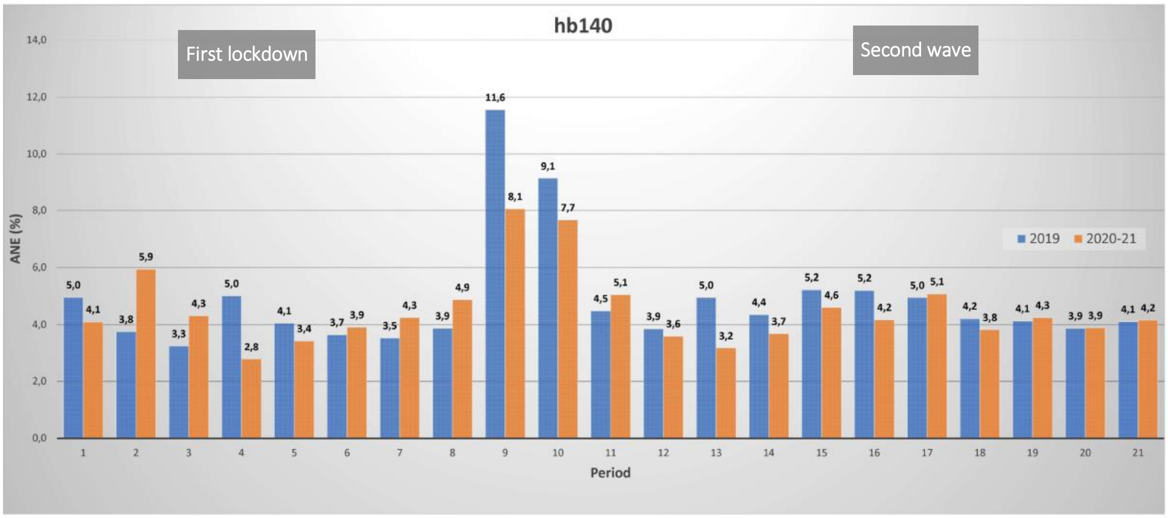

Figure 6 – Distribution of the ANE (%) detected by sensor hb140 (Viale Jenner) along the pre, during and post “hard” lockdown Periods from January 2020 to June 2021 with respect to the corresponding periods in 2019.

The impact of the presence of ANEs in the computation of the L_{den} values are shown in Fig. 7. It can be observed that 11 out of 21 values entail a correction of 0.5 dB(A) or higher. However, only 2 of them are higher than (or equal to) 1dB(A), being 1.5dB(A) and 1dB(A) during the lockdown for periods 4 and 5, respectively. Therefore, the presence of ANEs entails a higher impact on the RTN L_{den} measurement in sensor hb140 (Viale Jenner) as the ones observed in sensor hb127 (Via Quadrio) within the same period.

During the different post-lockdown stages, all the corrections are lower than 1dB(A), showing by the end of 2020 some quite relevant values around 0.7dB(A) (period 14-16, see Table 3). Both the summer of 2020 and the beginning of 2021 present a couple of periods with 0.5dB(A) corrections.

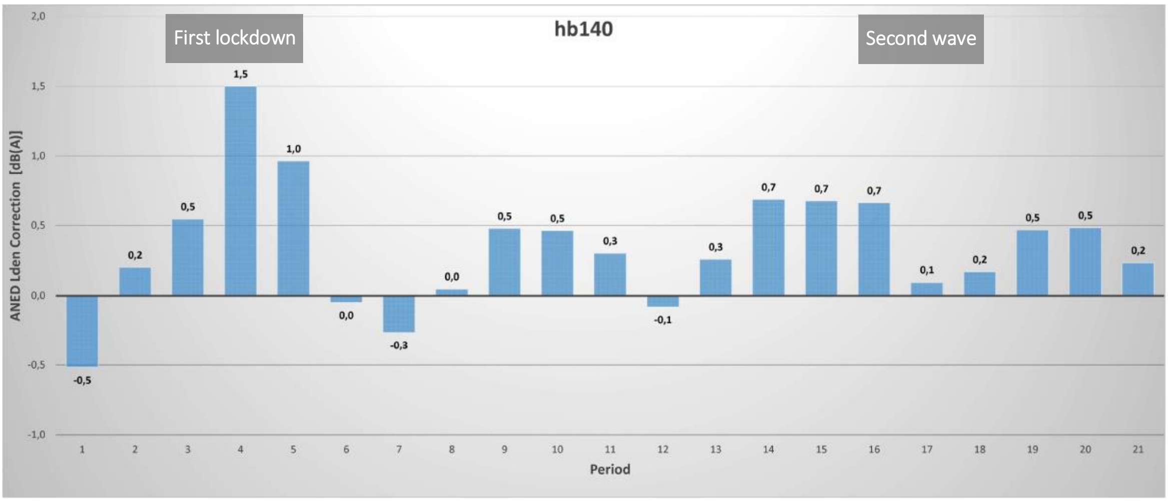

Figure 7 – Correction (in dB(A)) of the L_{den} values measured by sensor hb140 (Viale Jenner) caused by the presence of ANEs along the pre, during and post-lockdown Periods from January 2020 to June 2021.

4 Discussion

In this section, we discuss several aspects related to the conducted analyses. First of all, it is to note that, despite both monitoring stations present a similar global evolution on the L_{den} values, the overall levels of each location are quite different. The L_{den} values measured by sensor hb127 (Via Quadrio) are around 6 dB lower (8dB for L_{den} (ANED)) than those observed by sensor hb140 (Viale Jenner), besides presenting larger L_{den} reductions during both the "hard" lockdown and post "hard" lockdown periods. This is a relevant issue, since lower levels of RTN allows the detection of not only high-impact ANEs (e.g., sirens), but also low and mid-impact events (e.g., people talking) [12]. This difference can also explain the higher average of ANE (%) observed in sensor hb127 with respect to hb140, as well as the fact that the events detected by sensor hb140 during the progressive reopening do not surpass the ones detected in 2019, which differs from what is observed in the acoustic environment monitored by hb127. In a similar manner, despite there is a significant increment of ANEs (%) during the summer (periods 9-11 in Table 3), the ANE (%) observed in Viale Jenner in 2020 are lower than those from the corresponding period in 2019 as the summer in 2020 presents higher L_{den} values (see Figs. 2 and 6). Secondly, notice that no apparent correlation has been found between the increase of ANE (%) and the consequent correction of L_{den} (ANED) levels. For example, sensor hb127 (Via Quadrio) presents quite similar ΔANE (%) in periods 8 and 9 (see Table 3). Period 8 presents an ΔANE=3.8% that entails a correction of L_{den} (ANED) of 1.3dB(A), whereas in period 9, the 3.7% of ΔANE only causes a slight correction of 0.4dB(A) in the absolute noise level measurements. This result can be explained by the heterogeneous nature of the acoustic events, which may lead to low, mid or high individual and/or aggregate impacts on the equivalent noise levels computation (see [12] for further details). As periods 8 and 9 present a similar increment of ANEs with respect to 2019, we can conclude that the average impact of the events in period 9 is lower than in period 8 according to the bias caused in the L_{den} (ANED) values.

5 Conclusions

In this work, we have analysed the evolution of absolute traffic noise levels as well as the presence of ANEs at two representative DYNAMAP sensors located in the District 9 of Milan from January 2019 to June 2021.

The results confirm the L_{den} levels reduction during the lockdown, but with a greater decrease of the percentage of ANEs compared to previous works. Regarding the post-lockdown period, the summer of 2020 presents a particular behaviour, showing higher L_{den} levels and ANEs (%) than the same period in 2019. This result is mainly caused by the increase of vehicular traffic since the citizens of Milan remained in the city due to both the post-lockdown restrictions and the effects of the economic crisis. Afterwards, the sensed acoustic environments start getting back to normality, but still without returning to pre-COVID-19 levels. Moreover, we have also observed that the reduction of RTN allows a higher detection of ANEs, whose presence entails different variations on L_{den} values depending on their impact on the measurements. Future work will focus on extending the conducted analysis considering other monitoring stations.

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